CLIMATE CHANGE

Losing Arable Land, China Faces Stark Choice: Adapt or Go Hungry

To ensure food security, China is racing to develop new cultivars of staple grains that thrive in a warmer world

YUCHENG, CHINA—Hou Ruixing weaves his way through plots of winter wheat, stopping beneath an infrared heater suspended from wooden crossbars. The makeshift lamp and others arranged at 15-meter intervals at Yucheng Integrated Agricultural Experimental Station are simulating climate change by nudging up the thermometer an extra 1.6ºC—the average annual temperature increase that models predict will take hold here by 2030. Hou, a graduate student who lives 8 months a year on station grounds, points at two rows of wheat, explaining how traditional hand tilling and machine tilling trap different amounts of heat and water in the soil. "There are many experiments in the lab," Hou says. But nothing beats testing how new cultivars perform in the field.

Hard row to hoe. Warming is expected to trigger more episodes of heat stress that can sterilize the pollen of China's most important staple grain: rice.

Online
sciencemag.org
Podcast interview with author Christina Larson (http://scim.ag/pod_6120).

For half a century, Chinese scientists have been flocking to this spot on the eastern rim of the North China Plain, China's breadbasket, to probe pressing agricultural questions. The region just north of the Yellow River is ground zero for tackling food-security challenges such as flood control, drought, wind erosion, and soil alkalinity. To this list of concerns, researchers have now added climate change and its potential impact on grain yields. "We want to know how crops will reflect global warming," says Tao Fulu, an agricultural meteorologist at the Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences in Beijing.

Across the globe, scientists and policymakers are studying how climate change will affect agriculture. But in China, the question is especially urgent. The country has roughly 20% of the world's population but only 7% of its arable land—a share that is shrinking in the face of rapid urbanization. From 1998 to 2006, more than 860,000 hectares of arable land were swallowed up by cities each year on average, according to data from China's Ministry of Land and Resources. Changing dietary habits, meanwhile, are fueling a rapid rise in food consumption. Accompanying the expansion of China's middle class is a growing appetite for meat, which heaps more pressure on land and water resources. In 1978, China's total meat consumption was 8 million tons, but by 2012 it had ballooned to 71 million tons, according to the Earth Policy Institute, a think tank in Washington, D.C. In 2011, one-third of China's total grain harvest was converted to feed for livestock and aquaculture.

Climate change could exacerbate the fallout. According to the Chinese government's Second National Assessment Report on Climate Change in 2011, rising sea levels are likely to threaten China's eastern rice-growing regions by 2050, about the time that eight provinces in the north expect to face severe water shortages.

Already, annual mean temperatures near Yucheng rose 0.8ºC between 1955 and 2011, according to China Meteorological Administration (CMA) records. The uptick is felt most in winter and spring—coinciding with the growing season for winter wheat, the region's most important staple crop. Charting how warming affects various plant growth stages, from seed maturation to flowering to maturity, is "very important to understanding the impact of climate change," Tao says.

His group has discovered that contrary to conventional wisdom, rising temperatures in China's heartland are translating into shorter overall growing periods. Although warming accelerates the early stages of wheat growth, the length of the reproductive period—the phase spanning flowering and maturity—remains roughly the same for cultivars now commonly grown in the region. Tao and others are trying to tease out what that means for future yields, which are determined by grain number multiplied by the weight of each grain. "The number of grains is determined in the middle of the season, while the weight of each grain is determined during the reproductive phase," explains David Lobell, an agricultural scientist at Stanford University's Center on Food Security and the Environment in Palo Alto, California. At Yucheng, Lobell suggests, faster growth may mean fewer grains, spelling lower yields. Unless, that is, researchers develop cultivars better suited to the changing conditions, Tao notes.

By comparing records compiled by CMA and provincial agricultural departments between 1980 and 2008, Tao has attempted to tease out the climate signal from other factors affecting yield, such as crop management and fertilizer use. In a paper published online last October in *Climate Research*, Tao linked changes across China in temperature, precipitation, and solar radiation over those 3 decades with 1.3% and 1.7% reductions in projected wheat and maize yields, respectively. That translates to hundreds of thousands of tons

of lost harvest. A team at the Chinese Academy of Agricultural Sciences in Beijing and the International Food Policy Research Institute in Washington, D.C., has also identified a significant impact from climate change. They reported in *Agricultural and Forest Meteorology* in 2009 that warming caused a 4.5% decline in growth of wheat yields across China from 1979 to 2000.

Regional variation complicates the picture. In frigid northern China, where annual mean temperatures have risen faster than the national average, warming has extended arable land northward. But the potential agricultural benefits may be hard to reap, Tao warns, as climate change is expected to increase the frequency of drought and extreme weather events in an already water-stressed region.

Much of northern China is dry, making agriculture dependent upon irrigation from the Yellow River and the northern China aquifer. But pollution has degraded the quality of China's "Mother River" and growing cities are siphoning off water for urban uses. Some 120 billion cubic meters more water were pumped from the aquifer than were replaced by rainfall over the last 4 decades, resulting in a steadily retreating water table (*Science*, 18 June 2010, p. 1462). "The main problem in this region is water," Tao says.

In a pilot project launched in Yucheng in 2009, farmers are charged for the actual amount of water they draw from irrigation networks, rather than according to their acreage. Old concrete irrigation channels have been equipped with ultrasonic wave sensors to measure water levels; data are fed in real time to a local water-use association. On the experimental station's grounds, farmers can check their water usage data at a computer terminal set incongruously next to a mound of dried corn kernels.

In rice-growing southeastern China, warming may boost yields in the short term, but it is also likely to heighten damage from heat stress. "The increasing frequency of high temperature days is a risk factor," Tao says. Timing is critical: If rice is subjected to temperatures greater than approximately 37°C during pollination—as happened during a particularly roasting stretch during the summer of 2003—the pollen may be sterilized. "Even a brief exposure to high temperatures can lead to extremely reduced yields," says Jerry L. Hatfield, an agricultural scientist at the U.S. Department of Agriculture's Agricultural Research Service in Ames, Iowa.

Faced with such threats, China is mulling adaptation strategies. "The government doesn't yet have a very clear idea" of how to design adaptation policies, but it wants to understand the whole situation," says CMA scientist Zhou Guangsheng, who is compiling data on climate change and agriculture from Chinese research bodies. Among the trends he has noted so far is an upward spike in the frequency of weather-related disasters, including drought and wild temperature extremes.

Grain pains. Switching cultivars can improve crop resiliency, Tao says.

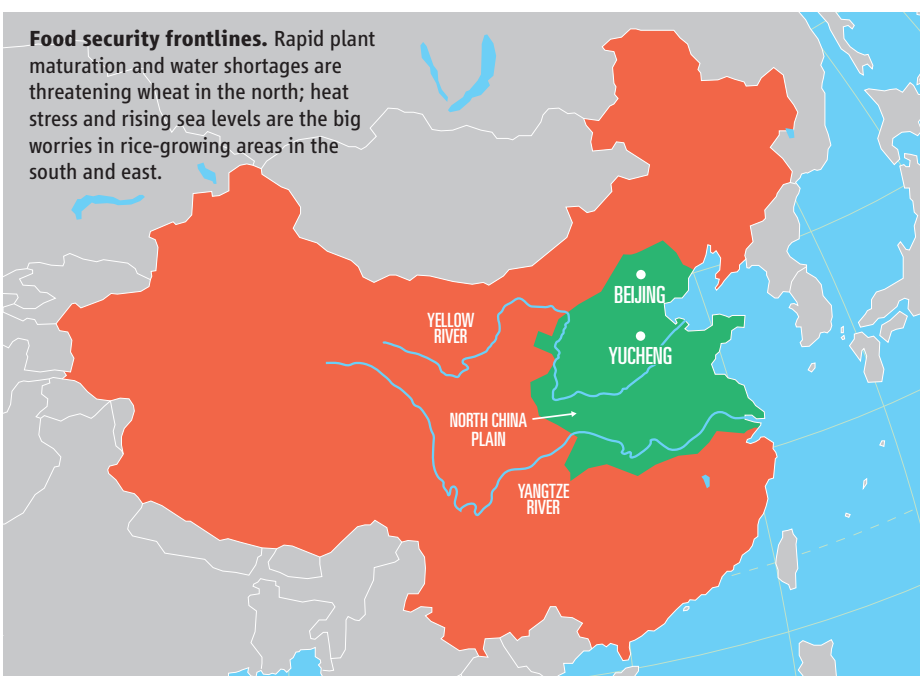
Potential adaptation strategies for food security include altering sowing and harvesting dates, adjusting irrigation schemes, and selecting or developing cultivars equipped to thrive in new climate conditions. Research from other parts of Asia could prove useful in China. At the Los Baños, Philippines–based International Rice Research Institute (IRRI), scientists are working to identify cultivars that release pollen during the early morning hours, before temperatures climb too high. The institute has also developed cultivars with greater flood and drought tolerance that are now in pilot trials in eastern India, where rice harvests largely depend on variable rainfall. "We are cautiously optimistic that we can develop rice varieties that will tolerate much of what climate change has to throw at us," says IRRI Director Robert Zeigler.

Back here in Yucheng, some locals are not waiting for a scientific verdict on how to adapt. Zhao Xiazhen, a 47-year-old farmer sporting a bright orange headscarf, says that in recent years, temperatures have been creeping up in late October, the sowing season for winter wheat. About 5 years ago, her family noticed that their wheat was growing more rapidly than before. If it were to mature too quickly, they would risk losing part of their harvest to frost damage; here, fast-maturing wheat plants are more fragile. To avert crop losses, they began delaying sowing by 5 or 6 days. Their harvests have held steady. Other farmers who have stuck with what has worked in the past haven't been so lucky, Zhao says: "Their crop was damaged."

Translating such observations into policy will ultimately require more research into shifting temperatures and precipitation patterns, says Li Yunsheng of the Institute of Geographic Sciences and Natural Resources Research. Employing a standard refrain for adapting any system to China's circumstances, Li says: "We are studying climate change with Chinese characteristics."

–CHRISTINA LARSON

Christina Larson writes on science in China.



Food security frontlines. Rapid plant maturation and water shortages are threatening wheat in the north; heat stress and rising sea levels are the big worries in rice-growing areas in the south and east.

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